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THE SOLUTION OF THE PROBLEM OF THE TIDAL BORE.

BY

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The marine phenomenon, the tidal bore, is a sight so very rare to the vast majority of people that, comparatively speaking, it is practically unknown; and yet its appearance is so very extraordinary that, were it known, it would be considered by every lover of nature an object well worth going a long distance to see. It occurs only in a very few rivers, and even in these few it does not always present itself at the time when it is expected. Sometimes it fails to appear—as in the case of the Severn and of the Solway, in Great Britain.

Prof. Geo. H. Darwin noted the fact of the failure in the Severn in "The Tides," and the writer observed the failure in the Solway. In the latter case there was no bore proper; instead there was only a small ripple—so very small, indeed, that an observer upon the shore failed to notice it; but from an upper window its upward progress was barely discernible upon the still, glassy surface of the firth. In a few rivers, however, the bore is permanent, and in two of these it attains very remarkable proportions—that is, in the Tsien-Tang, China; and in the Petitcodiac, New Brunswick, Canada. The former is by far the greater of the two, and is a veritable world-wonder.

Notwithstanding the rarity of this remarkable phenomenon, very little notice has been taken of it by scientists—so far as we are aware—and still less done towards the solution of it; and that little, so far as solving the problem is concerned, seems not only very unsatisfactory, but in some cases very unscientific. For example:

Prof. Arnold Guyot said that, "The bore is due to a struggle between the ascending wave and the opposing current of the stream." Were that theory correct, then bores would occur in every tidal river on earth, for every river current would create one!

Prof. Geo. H. Darwin made several statements with a view to the solution of the problem.

1. In one of his announcements he claimed that:

> It is due to the concentration of energy in a narrow space: when an estuary contracts, the range of tide is magnified.

In answer, it may be said that all estuaries become contracted, but very few indeed produce the bore. Nor is it true always that tides rise to their highest in contracted places. For instance, they rise much higher in the broad Firth of Clyde than in the contracted strait of the North Channel. "The energy of motion in the narrower space" of the North Channel fails totally to produce magnified tides, because the rise there is exceedingly small; whereas, on the contrary, the magnified tides take place in the wider Firth and in the widest part of its co-tidal basin, the Irish Sea. Yet, it is true that the power abiding in "the energy of motion in a narrow space," when brought into union with the precise conditions which cause the bore, is one of the attending conditions, but only one, and of itself, when standing alone, is utterly helpless.

2. In Mr. Darwin's second announcement he said:

> It would be impossible from the mere inspection of an estuary to say whether there would be a bore there; we could only say that the situation looked promising or the reverse. The capriciousness of the appearance of the bore proves that it depends on a very nice balance between conflicting forces, and the irregularity in depth and form of estuary renders the exact calculation of the form of the rising tide an impossibility. It would be easy to imitate the bore experimentally on a small scale, but we must rest satisfied with a general comprehension of the causes which produce it.

But he himself did not continue to "rest satisfied with a general comprehension of the causes," for afterwards he announced his third, and final, statement—a statement, by the way, of a decidedly revolutionary character compared with the first two and a total departure from the orderly methods of science:

> 3. Whence does this energy come [the energy of the bore]? Now, I say that it comes from the rotation of the earth.

THE TIDES.

His third attempt to solve the problem comes to us as a great surprise; and, strangely enough, it stands without the support of a single reason, or of an observed fact, to prove it, in "The Tides;" therefore it is merely a personal opinion, and nothing more. But that is not science. Yet, coming from such an authority, we pause to think how the new solvent will act. Were we to concede that the third statement is the correct theory, then we must confess that the rotating earth is able to carry everything along with it from west to east, except the Chinese bore! That it carries onwards the banks and the bottom of the river, and even the atmosphere above it, but not its flood tide! That, somehow or other (no reason given), the flood tide is left behind! It is also quite clear that the ebb tide is not affected by rotation; it is only the flood tide that is operated by it! Such a singular doctrine seems as if it had been conceived and brought forth in order to explain the *westerly* rush of the Chinese bore. But, as geographical students, we must not ignore the fact that the Canadian bore begins its rush in a *northerly* direction. In like manner, so does the Indian bore of the Hugli. The British bores in the Severn and the Solway travel *easterly*, and the French bore in the Seine travels *southerly*. In fact, to us, tidal bores are known to travel all round the compass; therefore, rotation does not enter into the problem at all. It is all a mistake.

THE BORE OF THE PETITCODIAC.

The bore of the Petitcodiac may be seen from one of the wharves of the town of Moncton. When one is perched upon one of these, as upon stilts, more than thirty feet above the bed of the river, towards the time of local low tide, the ebb seems to spend an unusually long time in taking its flight to the sea. In fact, it continues to flow seawards for the extraordinary space of nine hours, and at times even for nine and a half hours; but towards the expiry of that limit the broad river—nearly half a mile wide—becomes an empty river, with its shoals and flats everywhere in sight exposed to view; and in the lowest level there trickles a stream, only a few inches deep. Hence from such a puny rill, as compared with the swift, violent, inflowing tide, one does not get the faintest impression that a struggle between the two is possible.

Nor is it possible. Prof. Guyot, evidently, had never stood on the wharves at Moncton!

Nor is there any capriciousness in the appearance of the bore. It never fails to come. Sometimes the bore-breaker may have a frontal height of five feet, and again its height may be only three feet; but *it* is never capricious in the matter of its coming. When Prof. Darwin made his statement about the capriciousness of bores, evidently he, too, had never been an observer at Moncton!

The tidal bore is absolutely unlike an ordinary tide. It comes suddenly with a rush and a roar. It looks as if the sea had broken loose from its bounds. It can be seen and heard a mile away. Its bellowing, seething mass fills the whole breadth of the channel of the river. Its breaker falls with a crash like a breaker of the sea, for it travels very fast. At Moncton the rate of speed is 8.47 miles an hour—a very high rate for water. But it is not merely a breaker—a detached wave—like a breaker of the sea. It is the front of an inclined plane that rises higher and higher towards the sea! This is the feature that gives the impression that the sea has broken its bounds. Around the wharves the muddy waters surge and rapidly rise; sometimes the rise may be nine feet in seventeen minutes; at others it may take half an hour to make the same rise, but in any case the whole river is alive with the rushing flood, and soon is brimming full from bank to bank, thirty feet deep, and that in the extraordinarily short space of from three to three and a half hours. In other words, there has been an actual rise of forty-two feet above low-water level at the entrance of the river into the Bay of Fundy.

In our observation of the bore of the Petitcodiac we discern two abnormal local tidal conditions—1, The ebb is exceedingly long and slow; 2, the flood is exceedingly short and swift. These conditions are totally different from the usual tidal conditions of the Atlantic Ocean, therefore wholly local; but both are necessary towards the formation of the bore.

But still further, in connection with the abnormal local tidal conditions at Moncton, we must remember that tides are REGULAR at the entrance of the river. Hence, when tide is low at Moncton, it is half-tide at the entrance of the river—that is, it has risen twenty-one feet there. The river-bed at Moncton lies twelve feet above low-water level at the entrance of the river; hence, at half-tide, the level at the entrance of the river stands nine feet above low-water level at Moncton. In other words, precisely at the time of half-tide Moncton becomes a tidal sink, sunk nine feet below the level of the water in the Bay of Fundy (Cobequid Bay). This difference of level produces the energy of motion, the high rate of speed, and the inclined plane; and at a narrow reach of the river the steepness of the incline is accentuated, resulting in the formation of the bore. The bore does not begin at the entrance of the river, but eleven miles above it. The inflowing flood, however, travels these eleven miles in two hours to a place called Stony Creek. The river then becomes contracted, and the next 8.47 miles to Moncton is made in one hour. The total run of the bore is twenty-one miles. The total difference in low-water level between springs and neaps, and between one set of springs and another, is little more than one foot in summer and still less in winter. The special measurements here quoted are from the Report of Progress for 1899 of the Canadian Tidal Survey, under the superintendence of Mr. W. Bell Dawson, Ottawa. Mr. Dawson also draws attention to an extinct bore in the river Shubenacadie, Nova Scotia:

It used to go up to Maitland, but a change in the sand-bars below Maitland now prevents it; as the tide flows up the river, however, it still breaks occasionally into a ripple.

The silting named has destroyed the sink—one of the precise conditions requisite for the formation of the bore. From all this it follows that the necessary conditions for the formation of a bore are twofold—1, A region of high water-level standing at one end; 2, a deep sink lying towards the other end. These two conditions, of course, are only temporary—looking at them from the point of view of the length of duration of the flood tide—but when they do exist in union, then it follows that the weight and pressure in the region of higher level in a broad estuary must give an enormous energy of motion to the flood tide as it sweeps through the contracted channel into the inland tidal-sink beyond. It is also clear that the higher the region of high sea-level above the temporary tidal-sink, and the steeper the grade of the watery inclined plane, the greater will be the height of the bore-breaker and the faster its speed.

THE BORE OF THE TSIEN-TANG.

At the city of Haining the frontal aspect of this bore is a wall of water about one mile wide, ten feet high, and travelling at the rate of eleven miles an hour. This grand phenomenon was carefully observed by Capt. Moore, R.N., and his observations are among the official publications of the British Admiralty. A full account, however, is given in "The Tides," and that account is accompanied by a diagram (Diagram 18), which gives a very striking view of the abnormal tidal conditions necessary for the formation of the bore. Simultaneous observations were made at Haining and at two tidal stations in the estuary—Rambler Island and Volcano Island—but the centre of interest lies between Rambler Isle and the city. At the time of low tide the region round Rambler Isle becomes a tidal sink sunk three feet below the water-level at Haining and ten feet below the water-level at Volcano Isle; hence tides flow towards it from both places simultaneously at that time. The total rise of tide at Rambler Isle is given at twenty-three feet, and when tide is high there it is low at Haining—the distance between the two places is twenty-six miles. The total rise of tide at Haining is eighteen feet, and that rise is made in the very short space of three hours. (Precisely the same condition as in the case of the bore of the Petitcodiac.)

The tidal differences at the three stations are the following:

Tide falls 1 foot below mean sea-level, and rises 6 above, at Volcano Isle.

Tide falls 11 feet below mean sea-level, and rises 12 above, at Rambler Isle.

Tide falls 8 feet below mean sea-level, and rises 10 above, at Haining.

The total rise of tide is 7 feet at Volcano Isle.
" " " 23 " Rambler Isle.
" " " 18 " Haining.

From all this it is quite clear that when tide is high at Rambler Isle and low at Haining the slope of the watery inclined plane between the two places has a grade of twenty feet in twenty-six miles—a very steep grade indeed for sea-water. But within the limits of these twenty-six miles the boundaries of estuary and river become greatly contracted, and in the contracted region the angle of the slope becomes enlarged, and at the same time there occurs an increase in the energy of motion and of pressure. Hence, by reason of all this, when the accentuation in the inclined plane becomes too great to maintain the form of the plane, the frontal waters fall forward into the form of the bore-breaker.

The Tsien-Tang possesses the two prime conditions requisite for the formation of the bore:

A. The region of twenty feet high level, when tide is high at Rambler Isle.

B. The region of sink, when tide is low at Haining, sunk twenty feet below the high-water level at Rambler Isle.

These two conditions exist at the same instant of time. The opposition of the high level to a contiguous low level is always present at that instant of time; they are absolutely inseparable then. Hence the appearance of the bore is a necessary result of the opposition; and it likewise follows that this bore must have a greater frontal height, and an accelerated speed, because of its larger proportions, than that of the Petitcodiac. As is the sharpness of the angle of the inclined plane, so is the height of the bore-breaker. At Haining Capt. Moore estimated that one and three-quarter million tons of water passed the point of observation in one minute. The frontal height of the breaker is said to be higher now than it was during the Taiping rebellion, suppressed by the late Gen. Gordon. If that report is correct, then the swish of the awful current of this tremendous bore has dredged the sink deeper since that war.

With regard to the bore of the Tsien-Tang, Prof. Darwin made the singular remark, in "The Tides," that "There is no bore down stream." Of course not. A bore in the ebb tide is unknown there, and impossible, for the simple reason that the conditions are absolutely wanting at the time of ebb to form a bore. At that time the inclined plane stretches in one long, flattened plane from Haining to Volcano Isle, a distance of seventy-seven miles; and at the top of that plane there is no great region standing at high-water level, nor is there a region of low-water level at the bottom—a tidal sink—because at Volcano Island the extreme rise, or fall, is only seven feet.

It is now several years since we came to perceive the true cause of the bore, and only then after a visit to the Petitcodiac and a close study of its tidal conditions. By the fresher data of Capt. Moore—given in "The Tides"—and by a study of Mr. Darwin's elaborate diagram therein, we felt assured that our conclusion regarding the conditions which cause the bore was founded upon well-ascertained scientific facts, therefore the correct solution of the problem; and the only solution founded upon correct tidal observation, so far as we are aware.

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